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Original Research Article

Response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram *Vigna mungo* L. Hepper(Fabaceae)(country).

Abstract

Field experiment was conducted during the *kharif* season of 2019 to study the response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram (*Vigna mungo* L. Hepper).The initial soil parameter statuswerepH 4.6, OC 1.16%, medium in available soil N (256.99 kg ha^{-1}), low in available P (18.95 kg ha^{-1}) and medium in available K (212.56 kg ha^{-1}). The soil was well drained and sandy loam in texture The experiment was laid out in Factorial Randomized Block Design with three replications.The treatments consisted of four levels of phosphorus *i.e.* 0, 20, 40, 60 kg P_2O_5 ha^{-1} and four levels of biofertilizer *i.e.* uninoculated, *Rhizobium*, PSB, *Rhizobium* + PSB. Among the various treatment levels and sources, 60 kg P_2O_5 ha^{-1} with dual inoculation of seeds along with *Rhizobium*+ PSB significantly increased the growth and yield attributes such as plant height, plant population, Leaf Area Index (LAI), number of leaves $plant^{-1}$, number of branches $plant^{-1}$, Crop Growth Rate (CGR), number of pods $plant^{-1}$(30.72), pod length (4.68 cm), number of seeds pod^{-1}(7.20), seed yield (1120.35 kg ha^{-1}), stover yield (2401.54 kg ha^{-1}) and harvest index (31.80 %) over rest of the treatments. Results further indicated thata higher net return of INR39,811 and B:C ratio of 1.45 were also observed with the application of 60 kg P_2O_5 ha^{-1} along with dual inoculation of seeds with *Rhizobium* and PSB.

Keywords: Black gram, Phosphorus, Rhizobium, PSB, B:C ratio**(Do not remove words from the title to compose the keywords.)**

1. Introduction

Black gram is widely grown in India and other Asian countries as a pulse crop. About 19% area in India accounts for total pulse growing area contributing 23% of total production of pulse crops. The area and production of black gram in India during 2020-21 were 4.6 million hectares and 24.5 lakh tons (Anonymous, 2020). Tamil Nadu is the leading producer of black gram in India (Anand *et al*., 2022). It is highly nutritious and contains 60% carbohydrates, 24% protein, 1.3% fats, minerals (3.2%), vitamin A, B_1 and B_3 and is 5-10 times richer in phosphoric acid (385 mg/100g) among pulses (Sasidhar*et al.*,2022).Due to its richness in protein and affordable to all including those of low income group people, it is therefore known as poor man's meat (Aslam *et al.*, 2010). It is a drought resistant crop but intolerant to frost and water logging (Jothimani and Arulbalachandran, 2020). Apart from this, black gram has the ability to restore the soil fertility and fix about 22.10 kg of atmospheric N to meet the nitrogen demand through its root nodules (Saren*et al.*, 2017). Thus, this crop has been proved to require less amount of nitrogen due to its nodulation (Pandey *et al*., 2018). It is generally a warm season crop but it can be grown both in summer and winter in India. Phosphorus is an important macronutrient required by the plants right from the seedling stage to maturity. It plays significant role in growth with extensive root spread, flowering, enhanced nodulation, pod development and yield in legumes (Balyan*et al*., 2005, Yamuna *et al*., 2022). The deficiency of phosphorus in the soil adversely affect the growth, nodulation and yield in crops and global food security (Alikhani*et al*., 2006,Weikard 2016 and Heuer *et al*., 2017).Hence, phosphorus has been known as an importantmacronutrient element for yield increase, nutritional standardand for promoting earlier and more uniform maturity in legume crops (Singh *et al*., 2022).Biofertilizers are derived either from nodules of plants or rhizosphere and are capable of mobilizing the nutrients required by plants through natural process like atmospheric N fixation, solubilisation of P and also promote the growth of the plants by producing anti metabolites and hormones (Bhardwaj *et al*., 2014 and Mitter*et al*., 2021). It also increases the phosphorus availability to the plants through reducing P fixation, thus enhancing soil fertility (Arbad and Ismail, 2011). It has been used to promote sustainable agriculture through replacing chemical fertilizers (Wu *et al.*, 2005) and enhanced shelf life without affecting the ecosystem adversely (Sahoo *et al.*, 2014). Rhizobium is predominantly use for inoculating the black gram seeds which increases the N availability to plants and boost the growth as well as yield of the crop (Korir*et al.,* 2017) since it establishes symbiotic relationship with legume crops through nodulation and N fixation (Khuntia*et al*., 2022 and Masson-Boivin and Sachs, 2018). Similarly, inoculating the black gram seeds with Phosphate Solubilizing Bacteria (PSB) plays a vital role in supplementing P required by the crop. It helps in dissolving the interlocked phosphates by bringing out more amounts of unavailable and fixed phosphates in soil into soluble form and makes it available to plants (Elhaissoufi*et al*., 2022 and Barroso *et al*., 2006).Application of phosphatic fertilizers along with PSB is found to solubilise phosphate in the soil and increasethe phosphorus uptake by plants and thereby positively influenced the yield of the crop (Kalayu, 2019). Use of adequate fertilizers along with correct strain of biofertilizers play a pivotal role in achieving higher yield as well as higher economic return from black gram (Kumawat*et al.*, 2013). Thus, proper fertilization with proportionate amount of micro and macro nutrients is required to increase the productivity of pulse crops. Keeping in view the above discussion, the present experiment was conducted to observe the response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram (*Vigna mungo* L. Hepper).

Divide the introduction into at least 4 paragraphs.

2. Materials and Methods

A field experiment was conducted during the *kharif* season (August to October) of 2019 in the experimental farm of School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema campus. The physicochemical properties of the initial soil were pH 4.6, OC 1.16%, medium in available soil N (256.99 kg ha^{-1}), low in available P (18.95 kg ha^{-1}) and medium in available K (212.56 kg ha^{-1}). The soil was well drained and sandy loam in texture The experiment was laid out in Factorial Randomized Block Design with three replications. The treatment consisted of four different levels of phosphorus (0, 20, 40, 60 kg P_2O_5 ha^{-1}) and four different levels of biofertilizer *i.e.*uninoculated, *Rhizobium*, PSB, *Rhizobium* + PSB. Black gram variety PU-31 was sown @ seed rate of 15 kg ha^{-1}. The seeds were sown in lines with a spacing of 30 cm × 10 cm apart at a depth of 3-4 cm. Recommended dose of N @ 20 kg ha^{-1}, K @ 20 kg ha^{-1} and P levels @ 20, 40, 60 kg ha^{-1}were applied in the soil a day before sowing. The biofertilizer treatments*i.e.*Rhizobium and Phosphate Solubilizing Bacteria (PSB) were applied through seed treatment just before sowing @ 20 g kg^{-1} seeds. Intercultural operations and plant protection steps were carried out as per required. Various growth parameters, phenological observation and yield attributes were observed and recorded. All the obtained data from the experiment were processed, classified, tabulated andsystematically analysed with appropriate statistical methods (Which one? Anova, T test, Chi-square).

Where are the statistical values?

Divide the introduction into at least 3 paragraphs.

3. Result and Discussion

3.1. Growth Attributes

3.1.1.Plant height

The plant height of black gramwas increased significantly**(Statistical tests were not performed in the article. Therefore, you may not use the term significantly or not significantly)**with increase in thelevels of phosphorus as well as by inoculation of seeds with Rhizobium + PSB and 60 kg P_2O_5 ha^{-1} (Table 1). The highest was recorded at T_{16} which was at par with 40 kg P_2O_5 ha^{-1} + Rhizobium + PSB (T_{12}). This increased in plant height might be due to the involvement of P in the rhizosphere environment and plant system by enhancing the photosynthetic activity and plant metabolism thereby improving the plant growth and its development (Hakim*et al.* 2021) and due to the synergistic effect between phosphorus and biofertilizers converting the insoluble phosphates into soluble form for plant absorbtion (Jayshree and Umesha, 2021)

3.1.2.Plant population

The individual treatment with P as well as with dual inoculation of seeds with Rhizobium + PSB and 60 kg P_2O_5 ha^{-1} was found to decrease the mortality rate of plant population (T_{16}) significantly as compared to control(T_1)(Table 1). This might be due to the increasing levels of phosphorus application along with dual inoculation of seeds with Rhizobium+ PSB which results in better root development and root proliferation thereby reducing the plant mortality after germination (Gebremariam*et al*., 2021).

3.1.3. Number of branches plant^{-1}

Number of branches plant^{-1}were significantly influenced with increasinglevels of phosphorus as well as with dual inoculation of seeds with Rhizobium + PSB and 60 kg P_2O_5 ha^{-1}(T_{16})as shown in table 1. Similar finding was also reported by Kant*et al*., (2016).

3.1.4. Number of leaves plant^{-1}

The number of leaves plant^{-1} at harvest was found to be non-significantwith the application of phosphorus and biofertilizers (Table 1).

3.1.5. Leaf Area Index (LAI)

The Leaf Area Index (LAI) of the plant was significantly influenced with increased in the levels of phosphorus as well as with dual inoculation of seeds with Rhizobium + PSB and 60 kg P_2O_5 ha^{-1} (T_{16}) as shown in table 1. This might be due to the increase in the vegetative growthleading to more light interception andincreasing the leaf area index of the plants. Similar findings were also reported by

3.1.6. Crop Growth Rate (CGR) (g m^{-2} day^{-1})

The Crop Growth Rate (CGR) significantly increased with different levels of phosphorus treatment as well as with dual inoculation of seeds with *Rhizobium* + PSBand 60 kg P_2O_5 ha^{-1}(T_{16}) which was found at par with treatment (T_{12}) (Table 1). This resultwas in close conformity with the work done by Yadav *et al.* (2017).

3.1.7. Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$)

The RGR was non-significant in all the treatments individually or in combinations of phosphorus and biofertilizers at all the crop growth stages (Table 1).

3.1.8. Days to 50% flowering

The application of phosphorus and biofertilizers showed non-significant effect in all treatments with or without interactions on days to 50% flowering as shown in table 1.

3.1.9. Days to maturity

It was observed that the effect of phosphorus and biofertilizers had a non-significant effect in all treatments with or without interactions on days to maturity of plants as shown in table 1.

(Tables do not have standard deviation -statistics)

Table 1.Response of phosphorus and biofertilizers on growth attributes

Phosphorus × Biofertilizer	Plant height (cm)	Plant population (m^{-2})		Number of branches plant^{-1}	Number of leaves plant^{-1}	LAI	CGR (g m^{-2} day^{-1})	RGR (mgg^{-1}day^{-1})	Days to 50% flowering	Days to maturity
	At harvest	30 DAS	60 DAS	At harvest	At harvest	60 DAS	30-60 DAS	30-60 DAS		
T_1 (control)	33.00	30.89	29.22	4.20	4.07	1.12	2.18	0.022	41.00	68.00
T_2 (Control + Rhizobium)	36.07	34.55	32.66	4.47	4.20	1.23	2.97	0.023	40.33	68.00
T_3- P_0B_2 (Control + PSB)	38.87	34.11	31.77	4.33	4.27	1.26	2.90	0.023	40.67	68.00
T_4- P_0B_3 (Control + Rhizobium + PSB)	42.73	35.11	33.33	4.53	4.40	1.30	3.15	0.020	40.33	68.00
T_5- P_1B_0(20 kg P_2O_5 ha^{-1})	35.83	34.77	33.00	4.27	4.33	1.22	2.95	0.022	41.00	68.00
T_6- P_1B_1(20 kg P_2O_5 ha^{-1} + Rhizobium)	45.03	35.66	34.11	4.60	4.60	1.50	3.62	0.020	40.00	67.33
T_7- P_1B_2 (20 kg P_2O_5 ha^{-1} + PSB)	43.00	35.44	33.77	4.53	4.67	1.52	3.34	0.021	40.00	67.33
T_8- P_1B_3(20 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	48.10	36.22	34.66	4.73	4.87	2.02	3.50	0.023	39.33	66.67
T_9- P_2B_0(40 kg P_2O_5 ha^{-1})	37.07	35.00	33.44	4.40	4.47	1.40	3.45	0.025	40.33	68.00
T_{10}- P_2B_1(40 kg P_2O_5 ha^{-1} + Rhizobium)	49.57	36.00	34.89	4.67	4.80	1.84	3.87	0.023	40.33	66.67
T_{11}- P_2B_2(40 kg P_2O_5 ha^{-1} + PSB)	45.97	35.78	34.22	4.67	4.73	1.92	3.72	0.021	39.33	66.67
T_{12}- P_2B_3(40 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	53.10	37.44	36.11	5.13	5.20	2.30	4.58	0.026	39.00	66.00
T_{13}- P_3B_0(60 kg P_2O_5 ha^{-1})	41.53	35.55	34.00	4.53	4.53	1.65	3.67	0.021	39.67	67.33
T_{14}- P_3B_1(60 kg P_2O_5 ha^{-1} + Rhizobium)	50.10	36.55	35.66	5.00	4.80	2.07	4.08	0.023	39.33	66.00
T_{15}- P_3B_2(60 kg P_2O_5 ha^{-1} + PSB)	49.83	36.55	35.44	4.80	4.80	2.22	4.05	0.023	39.67	66.00
T_{16}- P_3B_3(60 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	55.00	38.00	36.66	5.33	5.07	2.62	4.58	0.023	39.00	66.00
SEm±	1.14	0.43	0.34	0.07	0.12	0.05	0.12	0.003	0.29	0.55
CD (p=0.05)	3.30	1.25	0.99	0.20	NS	0.15	0.33	NS	NS	NS

3.2. Yield and Yield Attributes

3.2.1. Number of pods plant^{-1}

The effect of different levels of phosphorus as well as dual inoculation of seeds with Rhizobium + PSB and 60 kg P_2O_5 ha^{-1} increased the no. of pods plant^{-1}significantly with maximum being recorded at $T_{16}$and closely followed by T_{12}. The lowest was recorded at control (T_1) (Table 2). This increased in the no. of pods plant^{-1} might be due to the enhance activity of nitrogenase, nitrate reductase, N and P availability to the plant which led to increase growth and yield attributes (Gajera*et al.*, 2014).

3.2.2. Pod length (cm)

The length of pod was significantly increased by application of different levels of phosphorus as well as with dual inoculation of *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1} at harvest as compared to control and individual seed inoculation. Length of the pods were recorded maximum in treatment (T_{16})- 60 kg P_2O_5 ha^{-1} + Rhizobium + PSB) and remained at par with treatment (T_{12}) - 40 kg P_2O_5 ha^{-1} + Rhizobium + PSB (Table 2). This increased in length of the pods might be due to the vitalrole played by phosphorus in flowering, fruiting and seed development along with combine inoculation of Rhizobium +PSB that resulted in achieving higher number of pods per plant as well as pod length (Table 2). This might be because of the readily available soil nutrients to the plant and soil micro-organisms which thereby fixed N and positively affecting the nodulation, growth and yield attributes (Kumar., 2011). Divide into at least 2 paragraphs.

3.2.3. Number of seeds pod^{-1}

It was observed that different levels of phosphorus as well as with dual inoculation of *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1} significantly affect the no. of seeds pod^{-1}. The highest was recorded at T_{16} over the rest of the treatments (Table 2). Phosphorus plays an important role inenhancing the photosynthesis and photosynthetic activity, biomass production and translocation in various plant parts thereby increasing the no. of seeds pod^{-1} (Bilal*et al.*, 2021).

3.2.4. Test weight (g)

The effect of phosphorus and biofertilizers had a non-significant effect on test weight (1000 seed) of black gram as shown in table 2.This is due to the fact that the plant gentic? characters controlled the test weight of seed(Gajera*et al.*, 2014).

3.2.5. Seed yield (kg ha^{-1})

Application of phosphorus at various levelsas well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1} recorded the highest grain yield significantly at T_{16}over alone inoculation and control (Table 2). Treating the seeds with Rhizobium increases the fixation of atmospheric nitrogen and on the other hand PSB plays an important role in solubilizing the native phosphorus resulting in more phosphorus availability to the plants. There is a synergistic effect between the yield and growth attributes which ultimately led to the increased in seed yield with increased in the other counterparts (Kumawat*et al*., 2013).

3.2.6. Stover yield (kg ha^{-1})

With the application of different levels of phosphorus as well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1},the stover yield was increased significantly.The maximum stover yield was recorded at T_{16} (Table 2). This increased in stover yield was due to the positive effect of P,Rhizobiumand PSB in growth attributes with its absorption by the plant and rhizosphere (Jakhar*et al*., 2018).

3.2.7. Harvest Index (%)

Data revealed that application phosphorus at various levels as well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1} affect the harvest index significantly. The maximum was recorded at T_{16} while the lowest harvest index was recorded in treatment (T_1) as shown in table 2.This might be due to the involvement of the physiological activity in photosynthesis and its translocation to various parts of the plant having economic benefits (Nikfarjam *et al.*, 2015).

Table 2: Response of phosphorus and biofertilizers on yield and yield attributing characters							
Phosphorus × Biofertilizer	Number of pods plant^{-1}	Pod length (cm)	Number of seeds pod^{-1}	Test weight (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1 (control)	16.96	4.10	5.67	36.96	638.30	1955.66	24.60
T_2 (Control + Rhizobium)	18.92	4.22	6.10	38.20	696.82	1999.75	25.86
T_3- P_0B_2 (Control + PSB)	17.86	4.15	6.06	37.93	689.03	1996.60	25.65
T_4- P_0B_3 (Control + Rhizobium + PSB)	21.33	4.33	6.23	38.72	719.12	2011.45	26.32
T_5- P_1B_0(20 kg P_2O_5 ha^{-1})	20.60	4.12	5.96	38.00	679.20	1983.54	25.50
T_6- P_1B_1(20 kg P_2O_5 ha^{-1} + Rhizobium)	23.67	4.40	6.32	38.97	831.55	2210.16	27.33
T_7- P_1B_2 (20 kg P_2O_5 ha^{-1} + PSB)	24.25	4.34	6.25	38.90	821.00	2186.52	27.30
T_8- P_1B_3(20 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	25.28	4.50	6.55	39.32	866.28	2235.30	27.92
T_9- P_2B_0(40 kg P_2O_5 ha^{-1})	23.12	4.23	6.12	38.96	731.70	2012.57	26.67
T_{10}- P_2B_1(40 kg P_2O_5 ha^{-1} + Rhizobium)	25.62	4.54	6.60	39.30	885.58	2266.00	28.10
T_{11}- P_2B_2(40 kg P_2O_5 ha^{-1} + PSB)	24.78	4.48	6.48	39.28	863.56	2257.25	27.67
T_{12}- P_2B_3(40 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	28.72	4.62	6.85	39.52	1012.78	2300.36	30.56
T_{13}- P_3B_0(60 kg P_2O_5 ha^{-1})	25.60	4.37	6.17	39.12	788.17	2072.90	27.54
T_{14}- P_3B_1(60 kg P_2O_5 ha^{-1} + Rhizobium)	28.12	4.54	6.70	39.40	977.45	2276.72	30.03
T_{15}- P_3B_2(60 kg P_2O_5 ha^{-1} + PSB)	27.95	4.52	6.62	39.35	960.08	2274.85	29.67
T_{16}- P_3B_3(60 kg P_2O_5 ha^{-1}+ Rhizobium + PSB)	30.72	4.68	7.20	39.82	1120.35	2401.54	31.80
SEm±	0.40	0.03	0.06	0.23	23.70	36.69	0.39
CD (*p*=0.05)	1.15	0.08	0.18	NS	68.46	105.98	1.11

3.3. Economic Analysis

The economics data on the response of phosphorus levelsas well as dual inoculation of seed with *Rhizobium* + PSB and 60 kg P_2O_5 ha^{-1} on black gram is shown in table 3. The common cost of cultivation for all the treatment was recorded atINR25,830 ha^{-1}. Application of 60 kg P_2O_5 ha^{-1} + Rhizobium + PSB (T_{16}) recorded the highest cost of cultivation (INR27,410.0 ha^{-1}) while, the lowest cost of cultivation (INR25,830 ha^{-1}) was recorded in control (T_1).It was observed that highest gross return (INR67,221.0 ha^{-1}) was observed with application of 60 kg P_2O_5 ha^{-1} + Rhizobium + PSB (T_{16}). The reason behind the higher gross return is due to higher input cost as compared to the rest of the treatment. The highest net return (INR39,811.0 ha^{-1}) was recorded under the same treatment *i.e.*60 kg P_2O_5 ha^{-1} + Rhizobium + PSB (T_{16}). The increase in net return in treatment (T_{16}) is due to higher seed yield and straw yield over control. The highest B:C ratio (1.45) was recorded in application of 60 kg P_2O_5 ha^{-1} + Rhizobium + PSB (T_{16}) while, the lowest (0.48) was recorded in control (T_1). The abovemention economic results were supported by the findings done by Gajera*et al.* (2014).

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Table 3: Response of phosphorus and biofertilizers on economic indices of black gram

Treatment	Cost of cultivation (INR ha^{-1})	Gross return (INR ha^{-1})	Net return (INR ha^{-1})	B:C ratio
T_1- P_0B_0	25,830	38,298	12,468	0.48
T_2- P_0B_1	25,870	41,809.2	15,939.2	0.61
T_3- P_0B_2	25,870	41,341.8	15,471.8	0.59
T_4- P_0B_3	25,910	43,147.2	17,237.2	0.66
T_5- P_1B_0	26,330	40,752.0	14,422	0.54
T_6- P_1B_1	26,370	49,893.0	23,523	0.89
T_7- P_1B_2	26,370	49,260.0	22,890	0.86
T_8- P_1B_3	26,410	51,976.8	25,566.8	0.96
T_9- P_2B_0	26,830	43,902.0	17,072	0.63
T_{10}- P_2B_1	26,870	53,134.8	26,264.8	0.97
T_{11}- P_2B_2	26,870	51,813.6	24,943.6	0.92
T_{12}- P_2B_3	26,910	60,766.8	33856.8	1.25
T_{13}- P_3B_0	27,330	47,290.2	19960.2	0.73
T_{14}- P_3B_1	27,370	58,647.0	31,277	1.14
T_{15}- P_3B_2	27,370	57,604.8	30,234.8	1.10
T_{16}- P_3B_3	27,410	67,221.0	39,811	1.45
SEm±	-	1422.19	1422.26	0.05
CD (p=0.05)	-	4107.58	4107.80	0.15

4. Conclusion

Based on the results of the experiment, it can be concluded that the application of 60 kg P_2O_5 ha^{-1} along with dual inoculation of seeds with *Rhizobium* and PSB found to have a significant effect on improving the growth attributes, yield attributes as well as providing a higher net monetary returnover the rest of the treatments observed in black gram (*Vigna mungo* L. Hepper).

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